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# THE VISIBLE EFFECTS OF THE SCHUMANN RAYS ON PROTOPLASM<sup>1</sup>

W. T. BOVIE

Since the pioneer studies of DOWNES and BLUNT, a large number of investigators have studied the effects of ultra-violet light on protoplasm. Their investigations, however, have all been made on the effect of light of wave lengths longer than 2000 Angstrom units. This paper is a preliminary report of the visible effects produced in protoplasm by light waves shorter than 2000 Angstrom units.

When studying the biological effects of light, it is convenient to divide the spectrum into the following regions:

Regions	Wave lengths in Angstrom units
Infra-red.....	from 10,000 to 7,200
Visible.....	“ 7,200 “ 4,000
Ultra-violet of sunlight.....	“ 4,000 “ 2,950
Quartz ultra-violet.....	“ 2,950 “ 1,850
Fluorite ultra-violet.....	“ 1,850 “ 1,250
(Schumann region.....	“ 2,000 “ 1,250)
Lyman region.....	“ 1,250 “ 900

To this series we may add Rontgen rays with wave lengths from 1 to 0.1 Angstrom units, and gamma rays with still shorter wave lengths.

The effect on protoplasm of light of the Schumann region of the spectrum is particularly interesting because in this region of the spectrum the destructive action of the light is much more violent than it is in regions of longer wave lengths. This violent action is undoubtedly connected with the fact that the Schumann region of the spectrum is a region of general absorption for nearly all substances. Even substances as transparent as air and water absorb the shortest Schumann rays. A layer of air 1 cm. thick or a layer of water only 0.5 mm.<sup>3</sup> thick absorbs all except the longest Schumann rays. Fluorite, the most transparent substance

<sup>1</sup> Preliminary communication.

<sup>2</sup> 10,000 Angstrom units = 1 micron.

<sup>3</sup> LYMAN, T., *Astrophysical Jour.* 27:87. 1908; *Nature* 84:71. 1910.

known, is the only solid which transmits the entire Schumann spectrum. It is interesting from a biological point of view to note that the absorption bands of such substances as egg-white and gelatin begin in the longer wave lengths before we reach the Schumann region.

In the writer's observations, to be described below, unicellular organisms were exposed to the Schumann rays and observed microscopically during and after the exposure. The Schumann rays were produced by a discharge tube which was so made that it could be placed under the stage of a compound microscope in the position usually occupied by the condenser and other sub-stage attachments. When the discharge tube was in place, its fluorite window, through which the Schumann rays were emitted, was flush with the microscope stage. The Schumann light shone upward toward the microscope objective. The organisms were exposed above the discharge tube on a special microscope slide which contained a window of fluorite (glass is opaque to these rays). The regular sub-stage attachments could then be swung into place and the organisms observed under high magnifications.

The effects produced by the light were immediate. There was a marked stimulation, followed by cytolysis, which, with a sufficient exposure, terminated in death. All of these changes were usually produced by an exposure of less than one minute's duration.

It was found that a given amount of exposure to the light produced the same effect whether the exposure were continuous or interrupted. This made it convenient to interrupt the exposure from time to time and to make a detailed study of the progress of the changes produced by the light.

The temperature of the drop of water containing the organisms was measured by means of a thermal junction, the variable junction of which was placed beside the organisms under the coverglass. As the temperature did not rise  $1^{\circ}$  C. during the experiment, the changes produced could not have been due to heat.

The length of time required for killing varied both with the species and with the individual organisms. In general, a small

organism was killed more quickly than a large one. With a given intensity of light, an exposure of several minutes was not sufficient to kill such organisms as rotifers and minute worms, while *Sphaerella*-like swarmspores, which contain both chlorophyll and an "eye-spot," were killed almost instantly. The swarmspores were killed so quickly that there was not sufficient change in temperature to be indicated by the thermal junction. The protoplasm of the swarmspores which had been killed by the light had a granular appearance. Often some of the protoplasm was extruded from the cell and was rounded up into drops.

The cells of a large *Spirogyra* of the *crassa* type were killed by an exposure of 45 seconds when the discharge tube was carrying 18 milliamperes. The various cell organs were affected quite differently by the exposure to the light; for instance, the nucleus became enlarged, while the chlorophyll bands contracted about it and became disorganized.

Active amoebae often showed very marked negative phototropism. The tips of their extended pseudopodia usually turned upward away from the light. Often a pseudopodium was pushed up from the upper surface of the body. The nucleus, together with a large portion of the granular endoplasm, flowed into this pseudopodium, leaving a clear ectoplasm below. With an amoeba in this condition, a properly timed exposure killed all of the lower part without killing the upper part; so that after the exposure, the protoplasm contained in the vertical pseudopodium moved away, leaving the coagulated lower part behind. In some cases, so much of the protoplasm flowed up into the pseudopodium that the amoeba became too heavy and toppled over. One amoeba was seen to send up a pseudopodium, to fall over, and then to repeat the process three times before it was killed.

Under the influence of the Schumann rays the endoplasm contracted, so that there appeared to be an increase in the amount of ectoplasm. The line separating the endoplasm from the ectoplasm was sharply defined. After a prolonged exposure, there was often a peculiar flowing of the granular endoplasm out into the ectoplasm. It did not appear to be the same kind of motion which one observes in the regular streaming of the protoplasm, but it was not easy to

say wherein the difference lay. After this all motion ceased and the protoplasm appeared coagulated. Under a high magnification (2200 diameters) the protoplasm was seen to be filled with small vacuoles which were so numerous that it had the appearance of a fine froth. These vacuoles were not visible before the organism was exposed to the light.

The length of exposure necessary to bring about these changes varied from 30 to 100 seconds when the hydrogen discharge tube was carrying 29 milliamperes. Since the effect on the organisms is additive, the entire exposure was not made at one time, but at intervals, so that the experiment often extended over an hour. Thus the changes produced by the light could be more carefully observed.

Infusoria are very quickly cytolyzed by the rapid vibrations of these ultra-violet rays. The nature of the cytolysis varies greatly with the species, and, in some of the minor details, it varies with different individuals.

The writer has observed three kinds of photo-cytolysis in ciliated infusoria: first, a cytolysis which is accompanied by the formation of vesicles on the surface; second, a cytolysis in which some of the internal portions of the protoplasm coagulate; and, third, a cytolysis in which some of the protoplasm disintegrates directly. The first two types of cytolysis were observed in *Colpoda*-like forms, and the third type was observed in *Stylonychia*.

The cytolysis by vesicle formation requires an exposure of about 30 seconds when the discharge tube is carrying 18 milliamperes. The vesicles are filled with a clear liquid and are often as large as the organism itself. Several vesicles may form and again disappear during the exposure. With sufficient exposure, the surface which separates the protoplasm from the fluid contained within the vesicle breaks, and the protoplasm flows out into the vesicle. A still longer exposure may cause the outer wall of the vesicle to rupture. The protoplasm then flows out into the surrounding water, with which it is miscible.

In the cytolysis in which parts of the protoplasm coagulate, an exposure of a few seconds results in the formation of small masses of coagulum, which are at once extruded by the organism. Con-

tinued exposure causes these coagulated masses to form faster than they are extruded. Soon a swelling appears, which bursts, and the protoplasm flows out.

In *Stylonychia*, the protoplasm disintegrates directly, and becomes miscible with the surrounding water. If the current of the discharge tube is increased to 60 or 70 milliamperes the disintegration begins at once. The infusorian darts across the field, leaving a trail of its cytolyzed protoplasm behind. The organism continues to move until only a few cilia with an attached mass of protoplasm is left intact, and this cytolyzes the instant motion ceases.

When thin-walled fungous spores are exposed to the light, the protoplasm either takes on a coagulated appearance, or the spore bursts. The spores which burst explode with such force that they are shot backward by the reaction. After the explosion a small mass of coagulated protoplasm is seen lying near the exploded spore.

This brief description of the visible effects of the Schumann rays is sufficient to indicate that these ultra-violet light rays have a most violent effect upon protoplasm. The writer has demonstrated by methods not described in this paper that the effect of the light is upon the organism itself and not upon the surrounding medium.

Vesicle formation and the bursting of spores point strongly to changes in osmotic relations or in imbibition, which may be connected with the fact, as shown in a previous paper,<sup>4</sup> that the longer ultra-violet light waves have the power to break down proteins. It will undoubtedly be found that these rays have a similar, and, judging from the violence of their action, a much greater power.

LABORATORY OF PLANT PHYSIOLOGY  
HARVARD UNIVERSITY

<sup>4</sup> Science N.S. 37: 24. 1913.